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MANUFACTURING WASTE DISPOSAL PRACTICES OF THE CHEMICAL PROPULSION INDUSTRY

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ABSTRACT

The waste production, mitigation and disposal practices of the United States chemical propulsion industry have been investigated, delineated, and comparatively assessed to the U.S. industrial base. Special emphasis has been placed on examination of ozone depleting chemicals (ODCs). The research examines present and anticipated future practices and problems encountered in the manufacture of solid and liquid propulsion systems. Information collected includes current environmental laws and regulations that guide the industry practices, processes in which ODCs are or have been used, quantities of waste produced, funding required to maintain environmentally compliant practices, and preventive efforts.

COMPARATIVE SIZE OF THE INDUSTRY

The U.S. gross national product (GNP) for 1994 has been estimated at approximately 6.7 trillion dollars. (1) The Aerospace industry accounts for approximately 92 billion dollars of manufactured goods, or 1.3% of the GNP. (1) It also accounts for a disproportionately high (approximate) 25% of the research and development "technology" expenditures in any given year. (1) Space propulsion units and parts, which equates in this paper to the chemical propulsion (CP) industry, accounts for approximately 3.7 billion dollars of the Aerospace total (~4%); this is approximately 0.06% of the GNP. (1) The research and development expenditures for space propulsion are similarly disproportionate within the total Aerospace expenditures. The resultant is that the chemical propulsion industry may account for 3% of the nation's research and development "technology" expenditures (calculated assuming a 10-15% fraction of Aerospace dollars, and based on approximately \$1,000,000 of the CP industry's total dollars). The following delineation is instructive in revealing the comparative size of the CP industry to other U.S. manufacturing areas: (1)

Aerospace:	\$	92,300,000,000
Aircraft		36,000,000,000
Aircraft engines and parts		13,300,000,000
Aircraft parts and equipment		12,500,000,000
Guided missiles/space vehicles		24,000,000,000
Space propulsion units and parts		3,700,000,000
Space vehicle equipment		1,980,000,000
Motor vehicles and parts (estimated for 1994)	\$	175,800,000,000
Net sales and revenue (GM, Ford, Chrysler-1992)		236,400,000,000
Profit (GM, Ford, Chrysler - 1992)		27,100,000,000
Petroleum products (1990) - U.S	\$	237,681,000,000

This paper presents specific issues related to the aerospace industry and samples of its advances in meeting pending legislation. The samples are taken from manufacturing waste practices of the four major United States space launch vehicles. These four vehicles are the Atlas, Delta, Titan, and Space Shuttle. A significant portion of the research, development, and technology insertion dollars from the chemical

propulsion industry are currently targeted at environmental issues associated with pending and existent legislation. The federal government has passed, and continues to pass, laws regulating hazardous waste generation. Figure 1 graphically depicts the increase in environmental laws in recent years. (2)

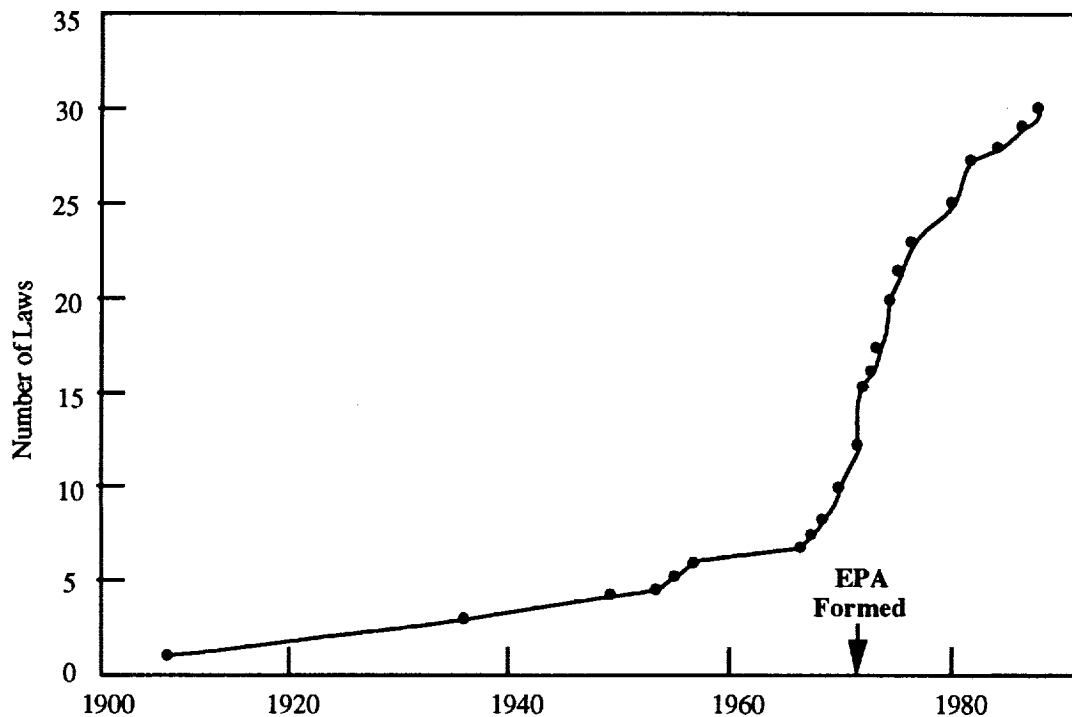


Figure 1. Major U.S. Legislation: 1906-1988

Much of the environmental legislation applicable to aerospace manufacturing processes is at the federal government level. The major federal laws and regulations affecting all aerospace manufacturers are listed as follows:

- Clean Water Act (CWA)
- Clean Air Act (CAA)
- Clean Air Act Amendments (CAAA)
- Resource Conservation and Recovery Act (RCRA)
- Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)
- Superfund Amendments and Reauthorization Act of 1986 (SARA)
- Federal Insecticide, Fungicide, & Rodenticide Acts (FIFRA)
- Hazardous Material Transportation Act (HMTA)
- Endangered Species Act (ESA)
- Toxic Substances Control Act (TSCA)
- National Environmental Policy Act (NEPA)
- Pollution Prevention Act (PPA)
- Occupational Safety and Health Act (OSHA)
- Oil Pollution Act (OPA)
- National Emission Standards for Hazardous Air Pollutants (NESHAPS)

The CAAAs have particular impact on the industry's use of ODCs. Title VI of the CAAAs divides the ODCs into two classes. Class I chemicals are CFCs, halons, carbon tetrachloride and methylchloroform. This group will be phased out by January 1, 1996. Class II chemicals are hydrochlorofluorocarbons (HCFCs) and will be completely phased out by January 1, 2030. (3)

The trend toward legislative controls is anticipated to continue. Currently, there are 159 NESHAPS planned for promulgation by the year 2000. The chemical propulsion industry appears to have significant impacts from approximately 34 of these at this time. Each industrial group will have 18 months (from promulgation) to get their reporting processes in place and three years for complete implementation and compliance. Following these impacts, legislation covering additional water resource concerns is anticipated.

ISSUES SPECIFIC TO THE INDUSTRY

While the manufacturers of the chemical propulsion vehicles face the elimination or reduction of Chlorofluorocarbons (CFCs), hazardous air pollutants (HAPs), volatile organic chemicals (VOCs) and accompanying legislation and Acts governing U.S. manufacturing, there is one substantive difference between this industry and many others. The chemical propulsion industry has critical, and precariously non-robust, technologies that govern the utilization of large liquid and solid propulsion systems.

Manufacturing aerospace components and assembly systems is a highly specialized process and demands an extraordinary degree of perfection. Specifications require that, after cleaning, parts are left with less than one milligram per square foot of contamination. Anything less than absolute cleanliness may have dramatic consequences. For example, unpredicted outgassing -- an accidental introduction of particles into the space environment -- can have an extreme consequence. Even the slightest residue can interfere with tiny valves; a single unwanted particle can clog a small bearing. Chlorinated hydrocarbons and CFCs, long the solvents of choice in aerospace and other precision manufacturing operations, are typically used to clean hardware in preparation for further manufacturing (e.g., machining, welding, coating, bonding) or final assembly. (4) The above legislated changes affect the chemistry involved in the cleaning, bonding, measurement and chemical constituents of the empirically derived databases that govern chemical propulsion system design and usage.

The replacement technologies required for the liquid and solid propulsion industries and the consequent technological challenges to the reliability and safety of the chemical propulsion systems are specific to the propulsion moiety. The solid industry has two current, significant, major challenges: pending elimination of 1,1,1 trichloroethane (TCA) and the disposal of waste propellants from current and past manufacture. Additional (and significant) funding is being targeted at ancillary vehicle systems (thrust vector control, avionics and paint/coatings) that, potentially, have other manufacturing industries addressing similar issues. The liquid propulsion industry's most significant problems are associated with the elimination of CFCs, and specifically CFC-113.

As before, it is instructive to provide comparative utilization values for those chemicals cited for elimination by the CP industry and the total U.S. manufacturing citations: (5,6,7,8)

Solid industry specific chemicals:

U.S. production of 1,1,1 trichloroethane (1992)	691,630,000 lbs
NASA utilization of TCA	1,000,000 lbs
CP industry utilization of TCA (estimated)	4,000,000 lbs

Liquid industry chemicals:

U.S. production of CFCs (1993)		257,000,000 lbs
NASA utilization of CFCs (1992)		644,904 lbs
CP industry utilization of CFCs (estimated)		2,000,000 lbs
U.S. production of CFC-113 (1991)	allowed	80,000,000 lbs
U.S. production of CFC-113 (1992)	allowed	60,000,000 lbs
U.S. production of CFC-113 (1993)	allowed	40,000,000 lbs
U.S. production of CFC-113 (1994)	allowed	15,000,000 lbs
NASA utilization of CFC-113 (1992)		404,251 lbs
CP industry utilization of CFC-113	estimated	1,200,000 lbs

Note: The estimated values for total chemical propulsion industry usage of TCA, CFCs and CFC-113 are taken by scaling the accurate NASA numbers to their relative portion of the thrust capability and materials to be cleaned within the industry. It has also been estimated that the current production is approximately three-fourths of allowed capacity.

These values may be conservative by up to 30%. It is readily evident that the solid industry represents approximately 0.5% of the TCA usage in the U.S. Similarly, the liquid propulsion industry represents approximately 0.8% of the total U.S. CFC usage and approximately 2% of the total CFC-113 usage. However, the chemical propulsion industry is providing a very significant portion of the research funding required for its specific needs in replacement technologies for TCA and CFC-113. NASA's portion alone may well exceed \$5 - \$10,000,000 exclusive of technology insertion and system (and new facility) development, test and qualification. (5)

To make a chemical propulsion system viable, the propellants must account for upwards of 85% of the mass of the system. Although the manufacture of these propellants (for liquids) is produced by subcontractors to the propulsion industry, and for solids is a complex mixture of materials provided by subcontractors, the significant proportion of these materials in a chemical propulsion system requires investigation for appropriately detailing the manufacturing impacts of the industry to the environment. Solid systems use approximately 20 million pounds per year whereas the liquid industry uses approximately 70 million pounds per year of propellants. Three propellants make up the majority of the U.S. liquid propulsion system usage: (1,9,10,11)

North American production capacity for hydrogen	225 short tons/day = 164,250,000 lbs/yr
NASA hydrogen utilization (1992)	11,000,000 lbs
CP industry hydrogen utilization (estimated)	20,000,000 lbs
U.S. production capacity for oxygen	6,750,020,000 lbs
CP industry utilization (FY93)	50,000,000 lbs
U.S. production of jet fuel	\$17,784,000,000
U.S. production of residual fuels	\$ 8,715,000,000
U.S. use of RP-1 (kerosene rocket fuel)	\$ 572,250

So the industry usage is approximately 12% of hydrogen production capacity, 0.75% of the manufactured oxygen capacity and 0.0065% of the fuels similar to rocket fuel manufactured yearly in the U.S. These values are again a small percentage of the total production.

Cleaning of cryogenic oxygen processing and propulsion equipment is critical to ensure product purity and safe operating conditions. The oxygen compatibility of materials is a function of local energy density and energy density rates, making the performance of materials in these environments a statistically predictable issue. Significant testing and data is required to adequately develop the statistical predictions. Higher energy density and rates (functions of purity, flow velocities, temperature and pressure) increase the likelihood of the occurrence of a combustion event. But it also increases the likelihood that the areas of significant concern reside further into the tails of the population. This results in significant issues solely relevant to the chemical propulsion industry, and the correspondingly high research and development expenditures.

The prime constituents in the manufacture of solid propulsion systems are ammonium perchlorate, rubber (binder) and aluminum. Twenty to 30 million pounds of ammonium perchlorate per year may be used. The primary constituents for this material are table salt (NaCl) and ammonium chloride. (10) This material usage represents a very small fraction of the salt and ammonia markets. The aluminum usage is covered below and the rubber material usage is minimal.

The solid propulsion manufacturing industry uses TCA as a vapor degreaser to clean adequately the large steel pressure vessels in preparation for bonding the insulation and propellant materials. These bondlines are one of the most critical feature of a solid rocket motor, inspection may be difficult and

debonds may be catastrophic. Again the margin for failure is limited and the requirements for cleanliness somewhat unique to this industry. Substantive progress has been made toward reduction of TCA usage in the majority usage processes (e.g., the vapor degreasing systems) but some critical processes, using less than 10% of the industry total usage, require significantly more research to qualify. Qualification for end product certification is also a substantive issue within the solid propulsion industry. Labscale testing, which is of relatively minor cost, often can not simulate the kinetic and thermodynamic effects present in large (or full scale) systems. Statistical testing of large systems is rarely possible; the shuttle redesigned solid rocket motor tests may cost upwards of \$15,000,000 apiece.

The solid industry also has an issue with disposal of scrap propellant and of the obsolete systems requiring destruction under existing arms control treaties. It has been estimated that approximately 140 million lbs of solid rocket propellants will require disposal between 1993 and 2005. (12) The Air Force, as the largest customer in this area, prepared a Statement of Operational Need (SON AFLC 003-90) in April of 1991 for "Solid Rocket Propellant Disposal". Compounding this issue, the number of disposal sites was reduced from approximately 1200 in 1980 to less than 200 in 1987. (12) Current data is unavailable, but open pit burning of propellants clearly has a limited useful lifetime.

It is instructive to compare the production of hazardous waste (per year) from the solid industry to that of the U.S. and chemical manufacturing industries: (1,2,12)

U.S. Hazardous Waste	~300,000,000 tons
Chemical Manufacturing Industry Hazardous Waste	~213,000,000 tons
Department of Defense Hazardous Waste	~650,000 tons
Solid Propulsion Industry	~6,500 tons

The solid industry's waste is divided as follows: (12)

Propellant - Residue	7,270,000	4,701,000
Propellant Testing	5,380,000	3,574,000
Other (inert, lab, etc....)	2,040,000	3,456,000
Solvents	979,000	1,143,000

These data reveal approximately a 20% reduction in the industry's waste streams and clearly define the largest issues to be propellant disposal. Overall however, the industry represents approximately 0.02% of the U.S. hazardous waste totals.

Compliance costs have also risen considerably. The Air Force has estimated that equivalent man-years associated with environmental compliance rose by approximately a factor of 10 between 1980 and 1990. (2,12) Substantive research in these areas is ongoing. Full implementation may cost in the hundreds of millions to low billions of dollars with anticipated recovery estimated in the low hundreds of millions of dollars. (2,12)

The use and manufacture of nitrogen tetroxide and hydrazines will not be explored within this paper. Their environmental constraints are among the most mature of the chemical propulsion manufacturing community due to their inherently hazardous nature.

The other major components of liquid and solid propulsion systems are the pressure vessels, which are either steel or aluminum. The industry uses on the order of 10 million pounds of steel per year versus the steel industry's U.S. consumption of 185 billion lbs, or 0.0054%. The chemical propulsion industry uses approximately 5 million pounds of aluminum versus the aluminum industry's 17.162 billion lbs (total shipment), or 0.03%. (1,11)

The total poundage of HAPs, VOCs and ODCs used by the chemical propulsion industry has been shown to be minimal, and the industry's contribution to the development of replacement technologies quite substantive. It is revealing to note an Environmental Protection Agency assessment that estimates that three years after promulgation of the Hazardous Organic Emissions Standard for Hazardous Air Pollutants the emissions at chemical plants should reduce by up to 1 billion pounds (or about 80%). (1) Usage by the

chemical propulsion industry of such chemicals clearly pales in comparison. This follows a reduction of 35%, by U.S. chemical producers, of toxic releases to the environment between 1987 and 1991. (1)

INDUSTRY ADVANCES IN MEETING PENDING LEGISLATION

The following information relates specific environmental advances in the manufacture of the Atlas, Delta, Titan and Space Shuttle, and relies solely on information shared by the vehicle contractors. It is not intended to be an exhaustive research of each aerospace company's use of ODCs, but rather a sample of ODC usage and the concerted efforts to reduce or eliminate their use.

Atlas

The Atlas II is a medium-lift commercial launch vehicle developed by General Dynamics Space Systems Division (GDSS) and manufactured in San Diego, California. This vehicle is primarily used by commercial interests. [Note: GDSS was recently purchased by the Martin Marietta Corporation (MMC) who also owns the Titan launch vehicle; however, the research for this document relies on data obtained while the Atlas was owned by GDSS].

The Atlas program has produced several significant environmental achievements in the production of the vehicle since 1990. TCA emissions have been cut 86% from 1990 to 1993 to save over 640 tons of TCA while production rates for precision cleaned hardware have been increasing. (13) For the period of July 1990 to May 1994, Atlas has eliminated historically derived use of 1,775,670 lbs of TCA. (14) The Atlas program cut both their division ozone-depleting emissions and their Form R-reported emissions 79% and achieved virtually zero air toxic health risk at their Kearny Mesa plant. (13) They have eliminated CFCs from precision cleaning and from nearly all other processes. "Industrial toxics" emissions have been reduced 57% from their 1988 baseline. These achievements have earned the Atlas Program environmental awards which include a 1992 Environmental Protection Agency (EPA) Stratospheric Ozone Protection Award and a 1993 San Diego Industrial Environmental Association "Environmental Responsibility Award." (13)

The Atlas Program has several initiatives planned for its Environmental Resources Management (ERM) program. Plans are to eliminate ozone-depleting emissions, reduce EPA "industrial toxics" emissions 90%, implement a comprehensive hazardous materials management program, eliminate air toxic-related health risks at the Kearny Mesa plant, develop and implement a "world class" ERM program, and implement a state-of-the-art alkaline precision cleaning process. (13)

Some of the program's ERM goals for 1994 include establishing a hazardous materials management program, eliminating TCA, TCE and CFCs from all processes, continue building a "world class" pollution prevention program, continue building a "world class" energy conservation program, and continue building "world class" regulatory compliance programs. (13)

Delta

The Delta II is a medium-lift commercial launch vehicle developed by McDonnell Douglas Aerospace (MDA) and manufactured in Pueblo, Colorado. Primary users are the Department of Defense (DoD), NASA, and commercial interests.

MDA is proceeding with its plan to replace ODCs currently being used in the manufacture of the Delta vehicle. MDA is working to select and implement substitute materials and processes to assure uninterrupted manufacture of their product. A schedule has been established to accomplish these goals in three phases: Phase 1 - define the problem; Phase 2 - define the solutions; and Phase 3 - implement the solutions by the end of 1996. (15)

The Phase 1 search of vapor degreasing requirements is almost complete. TCA is currently used for vapor degreasing operations. Isopropyl alcohol has been chosen as a replacement handwipe cleaner. (16)

Titan

The Titan launch vehicle was developed by Martin Marietta Corporation (MMC) and is manufactured at their plant in Denver, Colorado. MMC offers the Titan III for commercial and NASA uses, while the Titan IV is used primarily by DoD.

MMC has an environmental program actively in place to eliminate or significantly reduce hazardous wastes in the manufacture of the Titan vehicle. MMC has defined objectives to reach their environmental goals. They intend to drastically reduce the use of solvents and other toxic chemicals by identifying and implementing suitable alternative cleaning technologies and/or material substitutes. They will also work to reduce the company's exposure to existing regulations and future liabilities. (4)

These objectives are apparently already being met. MMC's pollution prevention projects have resulted in a combined reduction of 90% of toxic releases (base year of 1987). Total hazardous waste generation has been reduced from 1,100 tons in 1987 to 175 tons in 1992. (4)

TCA has been the favored solvent for Titan manufacturing operations involving first stage degreasing, a process which removes shop dirt as well as the fish-oil-like substance that coats and protects aluminum panels from corrosion. After an exhaustive search for a replacement, MMC chose a nontoxic aqueous cleaner called Daraclean 282 as an acceptable alternative to TCA vapor degreasing. MMC has now virtually eliminated its use of TCA, reducing annual consumption by 98% in 1991 compared to 1988. Daraclean 282 is biodegradable, easily recyclable, and has no known harmful environmental effects. There is no known employee health risk and it cleans surfaces better than the TCA it replaced. (4)

CFC-113 is generally used as the principal cleaner in the second stage of cleaning. The replacement search for this cleaner ended with isopropyl alcohol (IPA). IPA had been used successfully in other operations for over twenty-five years and met all performance requirements. Also, alcohol evaporates readily, leaving less residue than the other compounds tested. The new IPA cleaning system eliminates the use and release of approximately 55,000 pounds of CFC-113 a year. Distillation and volatile organic compound (VOC) treatment have also been added to the system, facilitating IPA recycling and reducing VOC releases to nearly zero. (4)

Space Shuttle

The Space Shuttle is manufactured by NASA in association with prime contractors Rockwell International, Rocketdyne, Martin Marietta, and Thiokol. Users thus far have been NASA, DoD, industry academia and international partners. The Space Shuttle is comprised of several major elements including the orbiter, external tank (ET), solid rocket boosters (SRBs) and Space Shuttle main engines (SSMEs). The focus of waste disposal for the Space Shuttle is on the ET, SRB, and SSME since new orbiters are no longer being manufactured.

External Tank. MMC is the primary contractor for the ET, which is manufactured at the Michoud Assembly Facility (MAF) in New Orleans, Louisiana. Several pollution sources originate from various ET production operations including aluminum barrel panel and propellant tanks cleaning, primer coating, sprayed-on foam insulation, liquid oxygen tank proof test and cleanliness verification. They are carefully monitored and handled to ensure safety and environmental compliance. Control systems designed to manage the sources and abate pollution include carbon adsorption, thermal oxidizers, air strippers, a hazardous waste storage facility, incinerators, and a solvent recovery system. (17)

In their pollution prevention effort, MMC has targeted chemicals in response to ODC phase-out, the EPA 33/50 commitment, and Louisiana Air Toxic maximum emission rates. The goals are to maintain methyl ethyl ketone emissions below 20,000 lbs (minor source), maintain chromium emissions less than 25 lbs and eliminate where possible, apply maximum available control technology (MACT) to dichloral methane emissions by 1996, eliminate CFC usage, and apply MACT to trichloroethylene (TCE) emissions by 1996. (17)

Space Shuttle Main Engine. Rocketdyne is the primary SSME contractor and is located at Canoga Park, California. Rocketdyne established a Hazardous Materials Elimination Team (HMET) in 1989. (18) HMET is actively pursuing methods to eliminate use of chrome, CFCs, TCA, VOCs, and other hazardous

chemicals from their manufacturing processes. Chrome is currently used in the following processes: chromic acid anodizing, chrome plating, zinc-chromated primers, and dry film lube containing chrome. CFCs are used for circuit board defluxing, hydraulic fluid particle counts, freon blown foam, cooling systems, and cleaning. TCA is used primarily for fine cleaning of parts. VOCs are used as solvent handwipes. All of these materials are scheduled for elimination. (19)

One of HMET's primary tasks is the elimination of ODCs. The group has been instrumental in the elimination of CFC-113, traditionally used as a solvent to clean electrical assemblies and rocket engine hardware. This was accomplished by modifying equipment and replacing the CFC solvent with other materials. The team has overseen an 85% reduction in Rocketdyne's use of TCA, which they use primarily in vapor degreasers for cleaning hardware. (18) They have deactivated 11 of 14 TCA vapor degreasers and made improvements to the remaining large units. In 1995, when TCA is totally eliminated from Rocketdyne's manufacturing processes, the facility will be converted to a water-based cleaning process. Rocketdyne is also eliminating Freon-11, another ozone-depleter that is used to apply insulation on the SSMEs. They have evaluated an alternative foam that uses carbon dioxide instead of Freon as the blowing agent. This new foam is being incorporated into the cryogenic insulation system of the SSMEs. (20)

Solid Rocket Boosters. Thiokol Corporation is the prime contractor for the Shuttle's SRBs. Their manufacturing facility is located near Brigham City, Utah, with refurbishment facilities near Ogden, Utah. A variety of ODCs are used in the manufacture of SRBs, most of which are undergoing replacement technology efforts. TCA is used for degreasing during refurbishment and manufacturing, tool cleaning, diluent, sling liner cleaning, floor usage, mixer bowl/blades cleaning, and critical hand cleaning, seal surface preparation, and rubber insulation activation. There has been a 50% reduction in TCA usage since 1989. Thiokol projects an 87% reduction by 1996 with total elimination by 2002. (21)

In their efforts to eliminate ODCs from the manufacturing process, Thiokol has developed a master schedule for replacement of all ODCs currently used. Thiokol plans a 90% ODC reduction for manufacturing processes by February 1996. The final 10% ODC reduction should be accomplished by 1999. (21) The company is in the midst of a five year, \$31 million program to eliminate ODCs from the solvents used for cleaning the solid rocket motors. The substitutes should be cost effective as well as environmentally safe. (22) Efforts have already begun paying off in the form of a 1993 EPA Ozone Protection Award. (23)

Efforts are focusing on new technologies such as ultrahigh-pressure water wash, spray-in-air cleaners, low emission vapor degreasing, surface cleanliness measurements, surface chemistry analyses, advanced vapor degreasing, and carbon dioxide pellet blasting. To further their efforts, Thiokol has formed partnerships with the NASA Operation Environment Team (NOET), NASA: Assured Shuttle Availability (ASA), NASA Headquarters - Environmental Engineering, the United Nations Solvents, Coatings, and Adhesives Technical Options Committee, the Aerospace Industries Association - Environmental Committee, Brigham Young University, and the University of Alabama in Huntsville. (21)

CONCLUSION

In summary, the chemical propulsion manufacturing industry is conducting a significant effort to pursue environmental replacement technologies for ODCs to assure compliance with federal laws and regulations. Efforts to date appear to concentrate on replacement of CFCs and TCA since the production and use of these chemicals are scheduled to be banned in the near future. The chemical propulsion industry represents a minute fraction of the production and production waste in the U.S., typically below 0.1% but is indicated at approximately 3% of the solution. The chemical propulsion industry's environmental issues are comparatively small but the industry has recognized those issues and is proactively addressing them in a manner that provides for technology transfer for the rest of the national industrial base.

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